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I. Garcia

J. H. Daniels

VARIABLES AFFECTING THE NEGATIVE MOMENT BEHAVIOR OF COMPOSITE BEAMS

by

I. Garcia
J. Hartley Daniels

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Fritz Engineering Laboratory
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Fritz Engineering Laboratory
Department of Civil Engineering
Lehigh University
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ABSTRACT

Six composite steel-concrete beams were tested under negative bending moments (slabs in tension). The purpose of these tests was to evaluate the effect of changing three design parameters. These parameters are:

(1) The perimeter ratio r of the longitudinal reinforcing bars. (Ratio of perimeter to area of all bars in the slab cross-section).

(2) The reinforcement ratio p of the slab. (Ratio of area of longitudinal reinforcement to the area of the slab cross-section).

(3) The free slab length d'/d. (Ratio of the length of slab without shear connectors to the length between the dead load points of inflection).

The six beams reported herein were designated SC-3S, SC-4S, SC-5S, SC-6S, SC-7S and SC-8S. Results of beams SC-3S and SC-4S are reported also in Ref. 1. All six beams were similar with respect to cross-section dimensions, span lengths and loading. Details are given in Ref. 1. Test results are discussed herein and in Chap. 8 of Ref. 2.

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1. INTRODUCTION

The purpose of the studies reported in Ref. 1 was

(1) To investigate the effect of the amount of longitudinal reinforcing steel in the slab, and

(2) To determine whether or not it is possible to simulate the negative moment region of a continuous composite beam by using a simple span beam subjected to negative bending moment.

It was evident from the results of the tests reported in Ref. 1 that simple span beams could be used to simulate the essential behavior of the negative moment regions of continuous composite beams. It was also evident that further experimental studies should be undertaken to evaluate the effect of changing three design parameters. The three parameters were:

(1) The perimeter ratio r of the longitudinal reinforcing bars. (Ratio of perimeter to area of all the bars in the slab cross-section).

(2) The reinforcement ratio p of the slab. (Ratio of area of longitudinal reinforcement to the area of the slab cross-section).

(3) The free slab length d'/d. (Ratio of the length of slab without shear connectors to the length between the dead load points of inflection).

These parameters are described in considerable detail in Ref. 2.

The six beams reported herein were designated SC-3S, SC-4S, SC-5S, SC-6S, SC-7S and SC-8S. The information obtained from the tests of SC-3S and SC-4S which are reported in Ref. 1 was used to design the four additional test beams. All six beams were similar with respect to cross-section dimensions, span lengths and loading. These details are given in Ref. 1. The six beams differed only in the variation of the three parameters mentioned above. The range of variation of parameters r, p and d'/d is shown in Table 1 of Ref. 2. The distribution of the longitudinal reinforcement in the upper layer of the slab is shown in Table 2 of Ref. 2.

The purpose of this report is to document the testing of the six beams SC-3S, SC-4S, SC-5S, SC-6S, SC-7S and SC-8S, and to make reference to other reports of this investigation for particular details and analysis of the test results. In addition to this report complete details of this investigation and analysis of test results are reported in Refs. 1 and 2.

2. TEST BEAMS, INSTRUMENTATION AND TESTING PROCEDURE

2.1 Description of Test Beams

Figure 15 (b) and (c) of Ref. 2 shows the details of the six simple span composite beams that were tested in this investigation. Each beam was centrally supported and subjected to loads at each end to produce negative bending moment (slab in tension) throughout the length of the beam. Each beam then simulates the negative moment region of a corresponding two-span continuous composite beam.

Each beam was 15'-4" long overall with a span of 12'-8" between load points. Each beam consisted of a reinforced concrete slab 60-in. wide and 6-in. thick, connected near the load points to a W21 x 62 rolled steel beam by 3/4 x 4-in. headed steel stud shear connectors.

Further details are reported in Art. 2.1 of Ref. 1 and Art. 7.2 of Ref. 2.

2.2 Design Criteria

The design criteria for the six beams reported herein are described in detail in Art. 7.3 of Ref. 2.

2.3 Design Details and Fabrication

Article 2.3 of Ref. 1 describes the design details and fabrication of test beams SC-3S and SC-4S. The details given were also the same for beams SC-5S, SC-6S, SC-7S and SC-8S. Additional details are shown in Fig. 1 of this report.

2.4 Construction

Refer to Art. 2.4 of Ref. 1.

2.5 Properties of the Test Beams

Article 2.5 of Ref. 1 describes the test program for determining the mechanical properties of the rolled steel beam used in tests SC-3S and SC-4S (Table 1 of Ref. 1). The steel beams for tests SC-6S and SC-7S were cut from the same length used for test SC-3S. Similarly the steel beam for tests SC-5S and SC-8S were cut from the same length used for test SC-4S.

The properties of all the reinforcing bars used for all six tests are shown in Table 1 of Ref. 1.

The results of the concrete cylinder tests for the six beams reported herein are shown in Table 1 of this report.

2.6 Instrumentation

Refer to Art. 2.6 of Ref. 1.

2.7 Test Procedure and Loading

Refer to Art. 2.7 of Ref. 1 and Art. 7.4 of Ref. 2.

3. TEST RESULTS AND ANALYSIS

The major presentation and analysis of the test results of the six beams reported herein is contained in Chap. 8 of Ref. 2. In that chapter, the test results were used primarily to evaluate experimentally the coefficient of participation C_1 of the free slab.

However, Arts. 8.4 to 8.9 of Ref. 2 present detailed discussions of the influence of the parameters r, p and d'/d on slab cracking, slip and slab separation, force distribution in the free slab, bending moment distribution, load-deflection behavior and stress distributions in the composite cross-section.

The major results of this investigation will be briefly summarized here together with some additional comments.

(1) Influence of perimeter ratio r:

Examination of Fig. 20 of Ref. 2 would indicate that the perimeter ratio r has a minor effect on the average crack widths.

(2) Influence of reinforcement ratio p:

Examination of Fig. 20 of Ref. 2 indicates that the reinforcement ratio is a major variable with respect to average crack widths. Comparison of beams SC-4S and SC-7S shows that a decrease in p from 1.02 to 0.89 percent resulted in twice the average crack width.

From the test results it is apparent that the minimum reinforcement ratio provided should be such that the tensile capacity of the reinforcement is at least equal to the tensile capacity of the concrete slab, and preferably somewhat greater. For example, using a concrete slab with f'_c = 4,000 psi and a tensile strength f'_t = 0.10 x 4,000 = 400 psi, and reinforcement with fy = 40,000 psi then the absolute minimum reinforcement ratio p is 1.0 percent. To prevent unrestrained increase in crack widths p should be somewhat greater.

All of the test beams had greater amounts of longitudinal reinforcement placed near the top surface of the slab for more effective control of cracking. The amounts varied from slightly more than 50% in the top layer for beams SC-3S and SC-5S to about 70% in the top layer for beam SC-4S.

(3) Influence of free slab length d'/d:

Examination of Fig. 20 of Ref. 2 indicates that the beams with the shorter free slab lengths exhibited the larger number of cracks. Therefore the free slab length is also a major variable.

The studies reported in Ref. 2 and the tests reported herein both indicate that the stress in the longitudinal reinforcement decreases as the free slab length is increased. However, the beneficial effect on crack width is offset by the larger length of slab not positively connected to the beam. In service, the free slab can separate from the beam due to differential shrinkage and temperature resulting in impact between the slab and beam during passage of live loads.

4. SUMMARY AND CONCLUSIONS

Six composite steel-concrete beams were tested under negative bending moments (slabs in tension) to evaluate the effect of three design parameters on the behavior of the test beams. These parameters were

(1) The perimeter ratio r of the longitudinal reinforcing bars.

(2) The reinforcement ratio p of the slab.

(3) The free slab length d'/d.

The complete results of these tests are presented herein and in Refs. 1 and 2.

Based on the tests described in this report and in Refs. 1 and 2, the following was concluded:

(1) The perimeter ratio r does not appear to play a major role in the beam behavior.

(2) The reinforcement ratio p is a significant variable. The reinforcement ratio must be greater than a certain minimum value to maintain slab cracks within tolerable limits. The centroid of the reinforcement should be nearer the top surface of the slab.

(3) The free slab length is an important variable and governs to a large degree the crack distributions and widths in the slab.

(4) The coefficient of participation C_1 of the free slab should be more extensively studied.

5. ACKNOWLEDGMENTS

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6. TABLES AND FIGURES

TABLE I

RESULTS OF CONCRETE CYLINDER TEST

	Standard Test			Cylinders Cured with Slab	
Beam	Tensile Strength (psi)	f_c' Compressive Strength (psi)	Modulus of Elasticity (ksi)	Tensile (psi)	Compressive (psi)
SC-3S	586	4690	3471	533	4580
SC-4S	587	5430	3940	530	4050
SC-5S	475	4280	3499		
SC-6S	409	4630	4030		
SC-7S	566	4780	4591		
SC-8S	562	4950	3668		

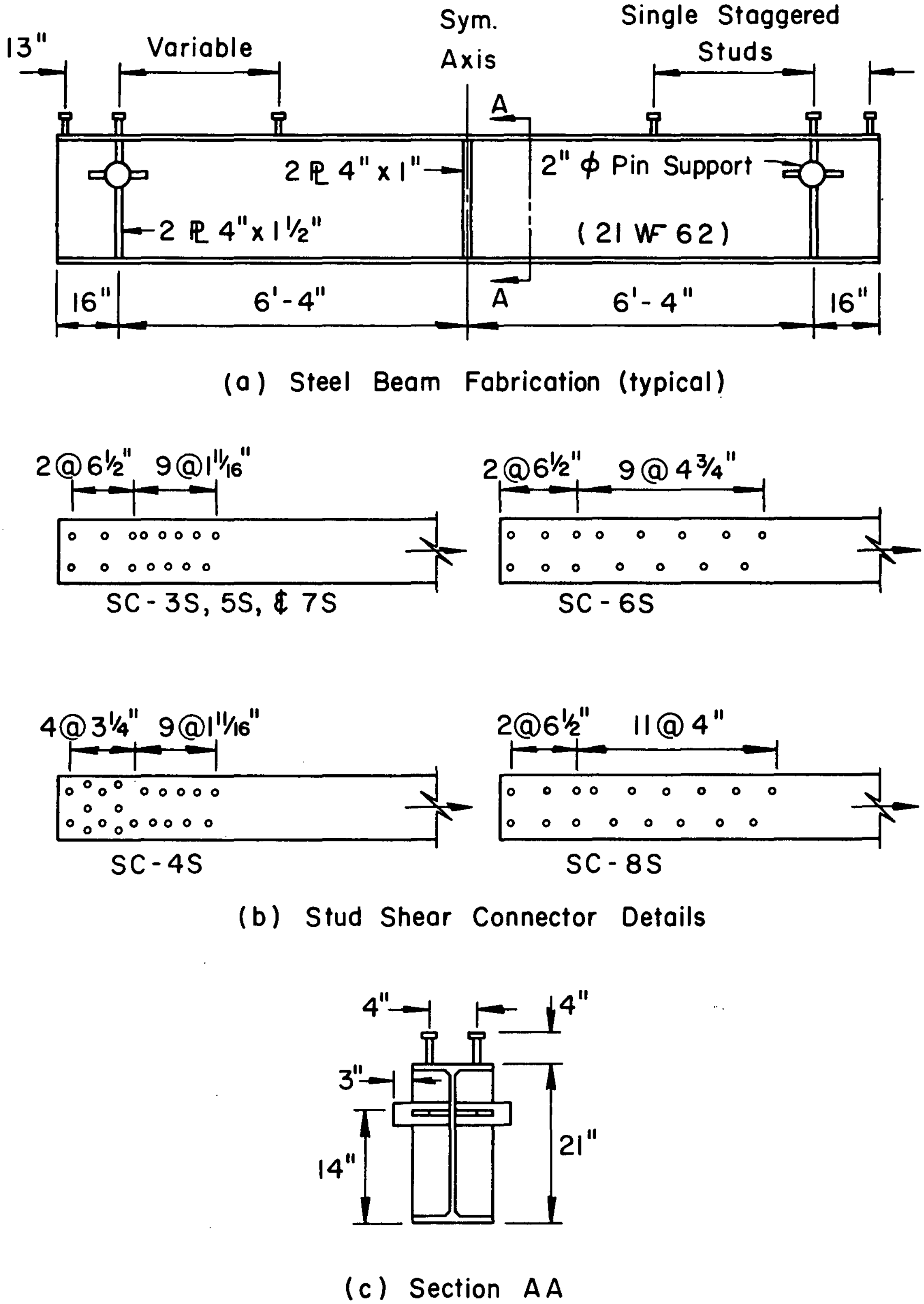

Fig. 1 Design Details and Fabrication

7. REFERENCES

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